# Scavenger Transceiver Module
# STM 400J

13 May 2013

**Observe precautions! Electrostatic sensitive devices!**

Patent protected:
WO98/36395, DE 100 25 561, DE 101 50 128,
WO 2004/051591, DE 103 01 678 A1, DE 10309334,
WO 04/109236, WO 05/096482, WO 02/095707,
US 6,747,573, US 7,019,241

EnOcean GmbH
Kolpingring 18a
82041 Oberhaching
Germany

Phone +49.89.67 34 689-0
Fax +49.89.67 34 689-50
info@enocean.com
www.enocean.com

## REVISION HISTORY

The following major modifications and improvements have been made to the first version of this document:

| No | Major Changes |
|---|---|
| 0.5 | Initial version |
| 0.6 | Update with more data |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |

**Published by EnOcean GmbH, Kolpingring 18a, 82041 Oberhaching, Germany**
**www.enocean.com, info@enocean.com, phone +49 (89) 6734 6890**

© EnOcean GmbH
All Rights Reserved

**Important!**

This information describes the type of component and shall not be considered as assured characteristics. No responsibility is assumed for possible omissions or inaccuracies. Circuitry and specifications are subject to change without notice. For the latest product specifications, refer to the EnOcean website: http://www.enocean.com.

As far as patents or other rights of third parties are concerned, liability is only assumed for modules, not for the described applications, processes and circuits.

EnOcean does not assume responsibility for use of modules described and limits its liability to the replacement of modules determined to be defective due to workmanship. Devices or systems containing RF components must meet the essential requirements of the local legal authorities.

The modules must not be used in any relation with equipment that supports, directly or indirectly, human health or life or with applications that can result in danger for people, animals or real value.

Components of the modules are considered and should be disposed of as hazardous waste. Local government regulations are to be observed.

Packing: Please use the recycling operators known to you.

# TABLE OF CONTENT

1 MODULE VARIANTS AND RELATED DOCUMENTS....4
2 GENERAL DESCRIPTION....4
2.1 Basic functionality....4
2.2 Technical data....5
2.3 Physical dimensions....5
2.4 Environmental conditions....6
2.5 Ordering Information....6
3 FUNCTIONAL DESCRIPTION....7
3.1 Simplified firmware flow chart and block diagram....7
3.2 Hardware pin out....8
3.3 Pin description and operational characteristics....9
3.3.1 GPIO supply voltage....11
3.3.2 Analog and digital inputs....12
3.4 Absolute maximum ratings (non operating)....13
3.5 Maximum ratings (operating)....13
3.6 Power management and voltage regulators....13
3.7 Charge control output (CCO)....14
3.8 Configuration....15
3.8.1 Configuration via pins....15
3.8.2 Configuration via programming interface....16
3.9 Radio telegram....17
3.9.1 Normal operation....17
3.9.2 Teach-in telegram....21
3.10 Transmit timing....21
3.11 Energy consumption....22
4 APPLICATIONS INFORMATION....23
4.1 How to connect an energy harvester and energy storage....23
4.2 Using the SCO pin....25
4.3 Using the WAKE pins....25
4.4 Using RVDD....27
4.5 Antenna options STM 400....28
4.5.1 Overview....28
4.5.2 Whip antenna....28
4.5.3 Helical antenna....28
4.6 Positioning of the whip antenna....29
4.7 Recommendations for laying a whip antenna....30
4.8 Layout recommendations for foot pattern....31
4.9 Soldering information....35
4.10 Tape & Reel specification....36
4.11 Transmission range....37
5 AGENCY CERTIFICATIONS....38
5.1 Japanese Type Approval....38

# 1 MODULE VARIANTS AND RELATED DOCUMENTS

This document describes operation of STM 400J modules with their built-in firmware. If you want to write own firmware running on the integrated micro controller or need more detailed information on the Dolphin core please also refer to:

- Dolphin Core Description
- Dolphin API Documentation

In addition we recommend following our application notes, in particular:

- AN102: Antenna Basics – Basic Antenna Design Considerations for EnOcean based Products
- AN207: ECS 300/310 Solar Panel - Design Considerations
- AN208: Energy Storage – Design Considerations
- AN209: STM 300 THERMO OR BATTERY POWERED – Power Supply Alternatives to Solar Panel

# 2 GENERAL DESCRIPTION

## 2.1 Basic functionality

The extremely power saving RF transmitter module STM 400 of EnOcean enables the realization of wireless and maintenance free sensors and actuators such as room operating panels, motion sensors or valve actuators for heating control.

Power supply is provided by an external energy harvester, e.g. a small solar cell (e.g. EnOcean ECS 3x0) or a thermal harvester. An energy storage device can be connected externally to bridge periods with no supply from the energy harvester. A voltage limiter avoids damaging of the module when the supply from the energy harvester gets too high. The module provides a user configurable cyclic wake up. After wake up a radio telegram (input data, unique 32 bit sensor ID, checksum) will be transmitted in case of a change of any digital input value compared to the last sending or in case of a significant change of measured analogue values (different input sensitivities can be selected). In case of no relevant input change a redundant retransmission signal is sent after a user configurable number of wake-ups to announce all current values. In addition a wake up can be triggered externally.

**Features with built-in firmware**

- 3 A/D converter inputs
- 4 digital inputs
- Configurable wake-up and transmission cycle

- Wake-up via Wake pins
- Voltage limiter
- Threshold detector
- Application notes for calculation of energy budgets and management of external energy storages

### Product variants

- STM 400J /

### Features accessible via API

Using the Dolphin API library it is possible to write custom firmware for the module. STM 400J is in-system programmable. The API provides:

- Integrated 16.384MHz 8051 CPU with 64 kB FLASH and 4 kB SRAM
- Receiver functionality
- Various power down and sleep modes down to typ. 0.1 µA current consumption
- Up to 16 configurable I/Os
- 10 bit ADC, 8 bit DAC

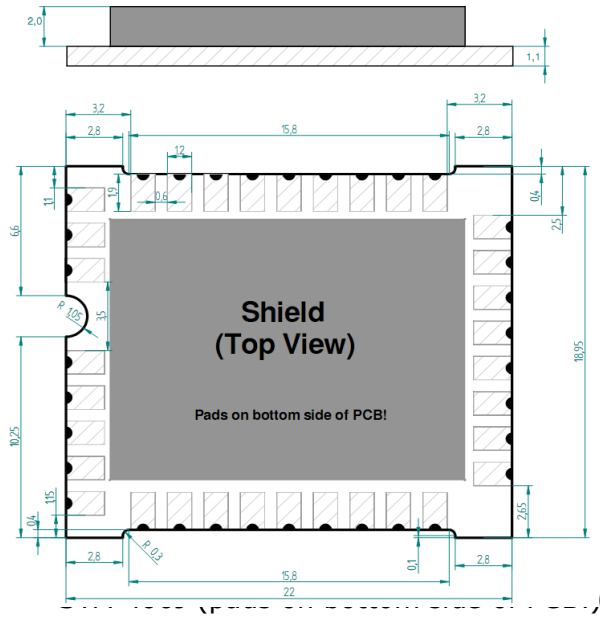
## 2.2 Technical data

| | |
|---|---|
| **Antenna** | External whip or 50 Ω antenna mountable |
| **Frequency** | 928.35 MHz (FSK) |
| **Data rate** | 125 kbps |
| **Receiver Sensitivity (at 25 °C)** only via API | typ. -95 dBm[1] |
| **Conducted Output Power @ 50 Ohm** | 0dBm |
| **Power Supply** | 2.1 V–5 V, 2.6 V needed for start-up |
| **Current Consumption** | Deep Sleep mode : typ. 0.1 µA<br>Transmit mode: typ. 16 mA<br>Receive mode (via API only): typ. 22 mA |
| **Input Channels** | 4x digital input, 2x WAKE input , 3x analog input<br>Resolution: 3x 8 bit or 1x 10 bit, 1x 8 bit, 1x 6 bit |
| **Radio Regulations** | ARIB STD-T108 |

## 2.3 Physical dimensions

| | |
|---|---|
| **PCB dimensions** | 22 x 19 x 3.1 mm |
| **Weight** | 1.9 g |

[1] @ 0.1% telegram error rate (based on transmitted sub-telegrams)




Unless otherwise specified dimensions are in mm.

Tolerances:
PCB outline dimensions ±0.2 mm
All other tolerances ±0.1 mm

## 2.4 Environmental conditions

| | |
|---|---|
| **Operating temperature** | -25 °C … +85 °C |
| **Storage temperature** | -40 °C … +85 °C |
| **Storage temperature in tape & reel package** | -20 °C … +50 °C |
| **Humidity** | 0% … 93% r.h., non-condensing |

## 2.5 Ordering Information

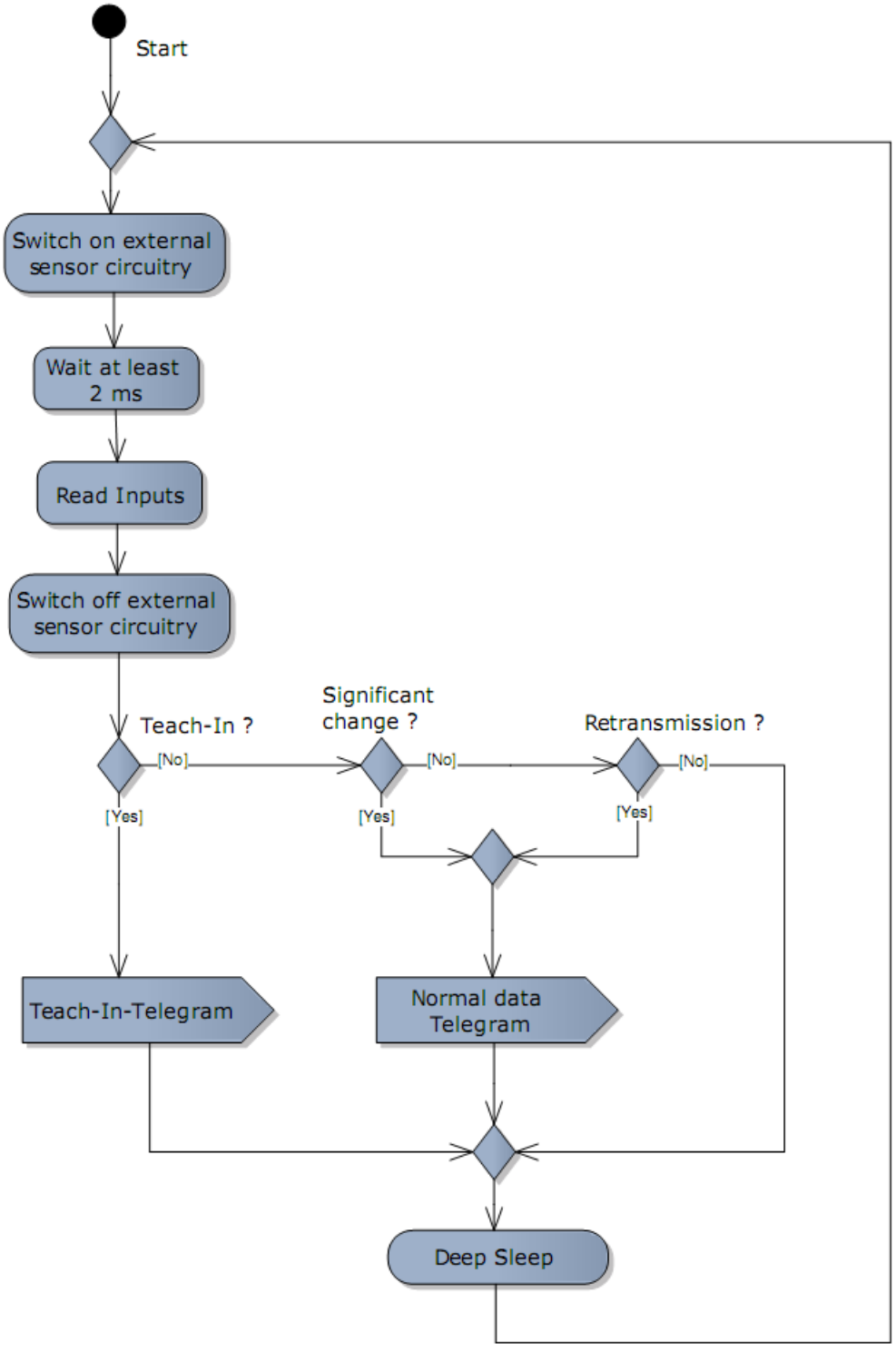
| Type | Ordering Code | Frequency |
|---|---|---|
| **STM 400** | **S3061-D400** | **928.35 MHz** |

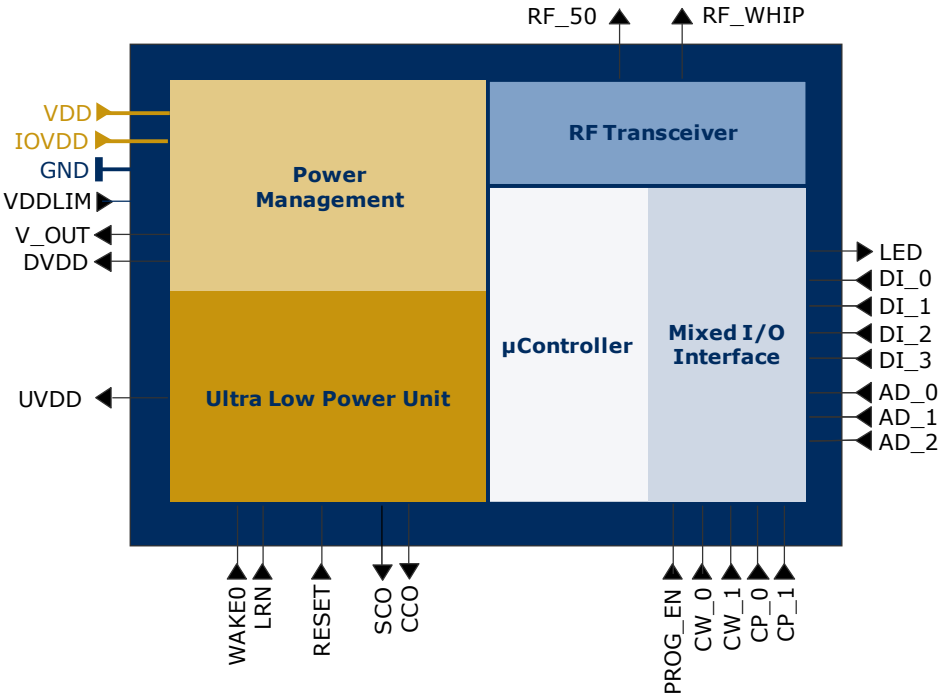
Suited solar cells (for technical details please refer to the ECS3x0 data sheet):

| Type | Ordering Code | Size |
|---|---|---|
| **ECS 300** | **S3005-D305** | **35.0 × 12.8 × 1.1 mm** |
| **ECS 310** | **S3005-D310** | **50.0 × 20.0 × 1.1 mm** |

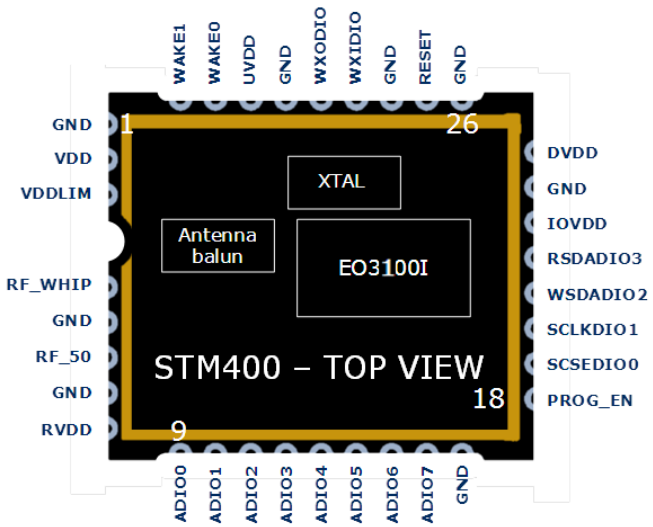
# 3 FUNCTIONAL DESCRIPTION

## 3.1 Simplified firmware flow chart and block diagram






## 3.2 Hardware pin out




The figure above shows the pin out of the STM 400 hardware. The pins are named according to the naming of the EO3100I chip to simplify usage of the DOLPHIN API.
The table in section 3.3 shows the translation of hardware pins to a naming that fits the functionality of the built-in firmware. When writing own firmware based on the DOLPHIN API please refer to the Dolphin Core Description and use this manual only for information

regarding the module hardware, such as pin out, layout recommendations, charging circuitry, antenna options, and approvals.

## 3.3 Pin description and operational characteristics

| STM 400 Hardware Symbol | STM 400 pin # | STM 400 Firmware Symbol | Function | Characteristics |
|---|---|---|---|---|
| GND | 1, 5, 7, 17, 24, 26, 28, 31 | GND | Ground connection | Must be connected to GND |
| VDD | 2 | VDD | Supply voltage | 2.1 V – 4.5 V;<br>Start-up voltage: 2.6 V<br>Maximum ripple: see 3.6 |
| RVDD | 8 | V_OUT | RF supply voltage regulator output | 1.8 V. Output current: max. 10 mA. See 4.4!<br>Supply for external circuitry, available while not in deep sleep mode. |
| DVDD | 25 | DVDD | Digital supply voltage regulator output | 1.8 V. Output current: max. 5 mA<br>Supply for external circuitry, available<br>while not in deep sleep mode. |
| UVDD | 32 | UVDD | Ultra low power supply voltage regulator output | Not for supply of external circuitry! For use with WAKE pins, see section 4.3.<br>Max. 1 µA output current! |
| VDDLIM | 3 | VDDLIM | Supply voltage limiter input | Limitation voltage: 4.5 V<br>Maximum shunting current: 50 mA |
| IOVDD | 23 | IOVDD | GPIO supply voltage | Must be connected to desired interface supply voltage as specified in 3.5, e.g. to DVDD. See also 3.3.1 |
| RESET | 27 | RESET | Reset input Programming I/F | Active high reset (1.8 V)<br>Connect external 10 kΩ pull-down. |
| PROG_EN | 18 | PROG_EN | Programming I/F | HIGH: programming mode active<br>LOW: operating mode<br>Digital input, connect external 10 kΩ pull-down. |
| ADIO0 | 9 | AD_0 | Analog input | Input read ~2 ms after wake-up.<br>Resolution 8 bit (default) or 10 bit.<br>See also 3.3.2. |
| ADIO1 | 10 | AD_1 | Analog input | Input read ~2 ms after wake-up.<br>Resolution 8 bit (default) or 6 bit.<br>See also 3.3.2. |
| ADIO2 | 11 | AD_2 | Analog input | Input read ~2 ms after wake-up.<br>Resolution 8 bit.<br>See also 3.3.2. |

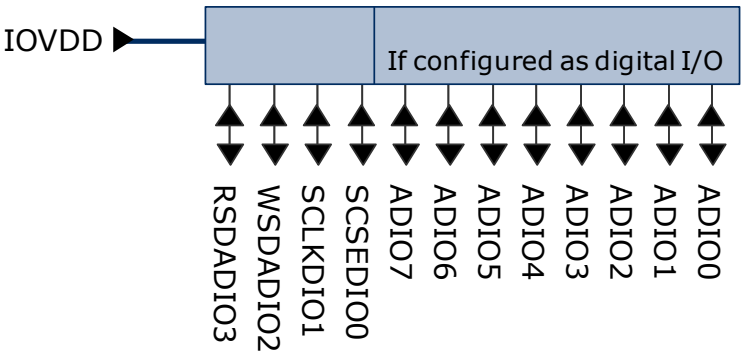
| | | | | |
|---|---|---|---|---|
| ADIO3 | 12 | DI_0 | Digital input | Input read ~2 ms after wake-up. See also 3.3.2. |
| ADIO4 | 13 | DI_1 | Digital input | Input read ~2 ms after wake-up. See also 3.3.2. |
| ADIO5 | 14 | DI_2 | Digital input | Input read ~2 ms after wake-up. See also 3.3.2. |
| ADIO6 | 15 | DI_3 | Digital input | Input read ~2 ms after wake-up. See also 3.3.2. |
| ADIO7 | 16 | LED | Transmission indicator LED | Max. output current:<br>2 mA @ IOVDD=3.3 V<br>0.65 mA @ IOVDD=1.8 V |
| | | | Programming I/F | |
| SCSEDIO0 | 19 | CW_1 | Encoding input for wake-up cycle | Leave open or connect to GND |
| | | | Programming I/F | |
| SCLKDIO1 | 20 | CW_0 | Encoding input for wake-up cycle | Leave open or connect to GND |
| | | | Programming I/F | |
| WSDADIO2 | 21 | CP_1 | Encoding input for retransmission | Leave open or connect to GND |
| | | | Programming I/F | |
| RSDADIO3 | 22 | CP_0 | Encoding input for retransmission | Leave open or connect to GND |
| | | | Programming I/F | |
| WXIDIO | 29 | SCO | Sensor control | Digital output, max. current 15 µA<br>HIGH ~x ms before analog inputs are read<br>(x=0…508 ms; default 2 ms.)<br>LOW at wake-up and after reading of analog inputs<br>Polarity can be inverted, delay time can be programmed, see 3.8.2. |
| WXODIO | 30 | CCO | Charge control | Max output current 15 µA<br>See 3.7 for description of behaviour. |
| WAKE0 | 33 | WAKE0 | Wake input | Change of logic state leads to wake-up and transmission of a telegram. See also 4.3. |
| WAKE1 | 34 | LRN | LRN input | Change of logic state to LOW leads to wake-up and transmission of teach-in telegram if a manufacturer code is programmed. See also 0 and 4.3. |
| RF_WHIP | 4 | RF_WHIP | RF output | Output for whip antenna |
| RF_50 | 6 | RF_50 | RF output | 50 Ohm output for external antenna |

### 3.3.1 GPIO supply voltage

For digital communication with other circuitry (peripherals) the digital I/O configured pins of the mixed signal sensor interface (ADIO0 to ADIO7) and the pins of the programming interface (SCSEDIO0, SCLKDIO1, WSDADIO2, RSDADIO3) may be operated from supply voltages different from DVDD. Therefore an interface supply voltage pin IOVDD is available which can be connected either to DVDD or to an external supply within the tolerated voltage range of IOVDD. Please note that the wristwatch XTAL I/Os WXIDIO and WXODIO are always supplied from UVDD.

If DVDD=0 V (e.g. in any sleep mode or if VDD<VOFF) and IOVDD is supplied, there may be unpredictable and varying current from IOVDD caused by internal floating nodes. It must be taken care that the current into IOVDD does not exceed 10 mA while DVDD=0 V.
If DVDD=0 V and IOVDD is not supplied, do not apply voltage to any above mentioned pin. This may lead to unpredictable malfunction of the device.

For I/O pins configured as analog pins the IOVDD voltage level is not relevant! However it is important to connect IOVDD to a supply voltage as specified in 3.5.



### 3.3.2 Analog and digital inputs

| Parameter | Conditions / Notes | Min | Typ | Max | Units |
|---|---|---|---|---|---|
| **Analog Input Mode** | | | | | |
| Measurement range | Single ended<br>Internal reference RVDD/2 | 0 | | RVDD | V |
| Input coupling | | | DC | | |
| Measurement bandwidth[2] | | | 62.5 | | kHz |
| Input impedance | Single ended against GND @ 1 kHz | 10 | | | MΩ |
| Input capacitance | Single ended against GND @ 1 kHz | | | 10 | pF |
| Effective measurement resolution | | | 10 | | Bit |
| **10 bit measurement – Final values to be confirmed after device characterization** | | | | | |
| Offset error | | | 23 | 36 | LSB |
| Gain error | | | 32 | 62 | LSB |
| INL | Code <=200 | | +3<br>-14 | +6<br>-23 | LSB |
| | Code >200 | | +3<br>-4 | +6<br>-10 | LSB |
| DNL | | | | <±0.5 | LSB |
| **8 bit measurement – Final values to be confirmed after device characterization** | | | | | |
| Offset error | | | 6 | 9 | LSB |
| Gain error | | | 8 | 16 | LSB |
| INL | Code <=50 | | +1<br>-4 | +2<br>-6 | LSB |
| | Code >50 | | +1<br>-1 | +2<br>-3 | LSB |
| DNL | | | | <±0.125 | LSB |

**Offset Error:** Describes the offset between the minimal possible code and code 0x00.
**Gain Error:** Describes the offset between maximum possible code and full scale (e.g. 0x3FF for 10 bit measurements).
**Integral Non-Linearity (INL):** Describes the difference between the ideal characteristics and the real characteristics. Only values between minimum and maximum possible code are considered (excluding offset error and gain error).
**Differential Non-Linearity (DNL):** Measures the maximum deviation from the ideal step size of 1 LSB (least significant bit).
**Effective resolution:** Results from the signal-noise ratio of the ADC and is given in Bit. The number describes how many bits can be measured stable. The criterion selected here is that the noise of DNL is <±0.5 LSB.
**Measurement Bandwidth:** The measurement bandwitdh is internally limited by filters. A quasi static signal must be applied as long as the filter needs to settle. SettlingTime= 1/(MeasurementBandwidth)*ln(2^resolution[Bit])

For further details please refer to the Dolphin Core Description.

[2] 3 dB input bandwidth, resulting in 111 µs settling time to achieve a deviation of an input signal <1 LSB (<0.098% @ 10 bit resolution).

| Parameter | Conditions / Notes | Min | Typ | Max | Units |
|---|---|---|---|---|---|
| **Digital Input Mode** | | | | | |
| Input HIGH voltage | | 2/3 IOVDD | | | V |
| Input LOW voltage | | | | 1/3 IOVDD | V |
| Pull up resistor | @IOVDD=1.7 … 1.9 V | 90 | 132 | 200 | kΩ |
| | @IOVDD=3.0 … 3.6 V | 38 | 54 | 85 | kΩ |

## 3.4 Absolute maximum ratings (non operating)

| Symbol | Parameter | Min | Max | Units |
|---|---|---|---|---|
| VDD VDDLIM | Supply voltage at VDD and VDDLIM | -0.5 | 5.5 | V |
| IOVDD | GPIO supply voltage | -0.5 | 3.6 | V |
| GND | Ground connection | 0 | 0 | V |
| VINA | Voltage at every analog input pin | -0.5 | 2 | V |
| VIND1 | Voltage at RESET, WAKE0/1, and every digital input pin except WXIDIO/WXODIO | -0.5 | 3.6 | V |
| VIND2 | Voltage at WXIDIO / WXODIO input pin | -0.5 | 2 | V |

## 3.5 Maximum ratings (operating)

| Symbol | Parameter | Min | Max | Units |
|---|---|---|---|---|
| VDD VDDLIM | Supply voltage at VDD and VDDLIM | VOFF | 5.0 | V |
| IOVDD | GPIO supply voltage (see also 3.3.1) | 1.7 | 3.6 | V |
| GND | Ground connection | 0 | 0 | V |
| VINA | Voltage at every analog input pin | 0 | 2.0 | V |
| VIND1 | Voltage at RESET, WAKE0/1, and every digital input pin except WXIDIO / WXODIO | 0 | 3.6 | V |
| VIND2 | Voltage at WXIDIO / WXODIO input pin | 0 | 2.0 | V |

## 3.6 Power management and voltage regulators

| Symbol | Parameter | Conditions / Notes | Min | Typ | Max | Units |
|---|---|---|---|---|---|---|
| **Voltage Regulators** | | | | | | |
| VDDR | Ripple on VDD, where Min(VDD) > VON | | | | 50 | $mV_{pp}$ |
| UVDD | Ultra Low Power supply | | | 1.8 | | V |
| RVDD | RF supply | | 1.7 | 1.8 | 1.9 | V |
| DVDD | Digital supply | | 1.7 | 1.8 | 1.9 | V |
| **Voltage Limiter** | | | | | | |
| VLIM | Limitation voltage | | 4.0 | 4.5 | 5.5 | V |

| | | | | | | |
|---|---|---|---|---|---|---|
| ILIM | Shunting current | | | | 50 | mA |
| **Threshold Detector** | | | | | | |
| VON | Turn on threshold | | 2.3 | 2.45 | 2.6 | V |
| VOFF | Turn off threshold | Automatic shutdown if VDD drops below VOFF | 1.85 | 1.94 | 2.1 | V |

**Voltage Limiter**
STM 400 provides a voltage limiter which limits the supply voltage VDD of STM 400 to a value VDDLIM which is slightly below the maximum VDD ratings by shunting of sufficient current.

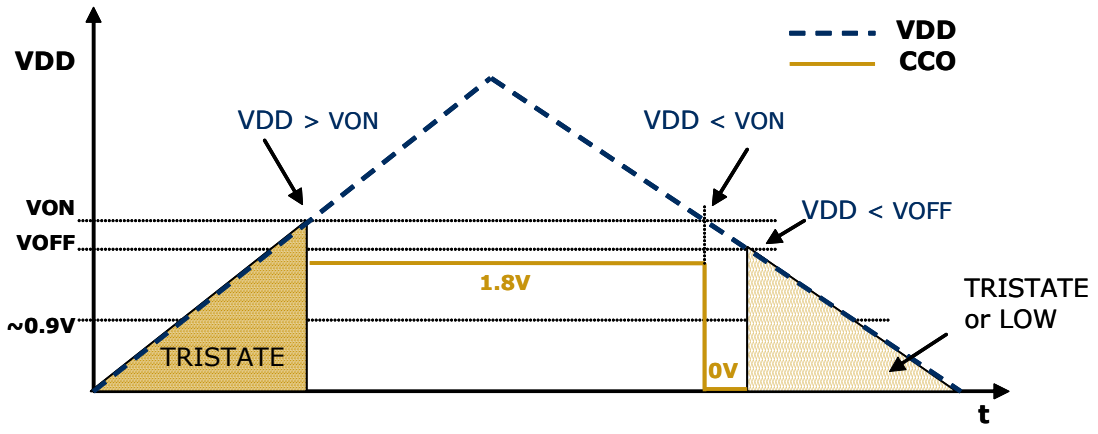
**Threshold detector**
STM 400 provides an ultra low power ON/OFF threshold detector. If VDD > VON, it turns on the ultra low power regulator (UVDD), the watchdog timer and the WAKE# pins circuitry. If VDD ≤ VOFF it initiates the automatic shut down of STM 400.

## 3.7 Charge control output (CCO)

After start-up STM 400 provides the output signal of the threshold detector at CCO.
CCO is supplied by UVDD. The output value remains stable also when STM 400 is in deep sleep mode.

**Behaviour of CCO**

- At power up: TRISTATE until VDD>VON then HIGH
- if VDD>VON then HIGH
- if VDD<VON then LOW
- if VDD< VOFF then LOW or TRISTATE




For definition of VON and VOFF please refer to 3.6.

## 3.8 Configuration

### 3.8.1 Configuration via pins

The encoding input pins have to be left open or connected to GND in correspondence with the following connection schemes. These settings are checked at every wake-up.

**Wake-up cycle time**

| CW_0 | CW_1 | Wake-up cycle time |
|---|---|---|
| NC | NC | 1 s ±20% |
| GND | NC | 10 s ±20% |
| NC | GND | 100 s ±20% |
| GND | GND | No cyclic wake-up |

**Redundant retransmission**

Via CP_0 and CP_1 an internal counter is set which is decreased at every wake-up signal. Once the counter reaches zero the redundant retransmission signal is sent.

| CP_0 | CP_1 | Number of wake-ups that trigger a redundant retransmission |
|---|---|---|
| NC | NC | Every timer wake-up signal |
| GND | NC | Every $7^{th}$ - $14^{th}$ timer wake-up signal, affected at random |
| NC | GND | Every $70^{th}$ - $140^{th}$ timer wake-up signal, affected at random |
| GND | GND | No redundant retransmission |

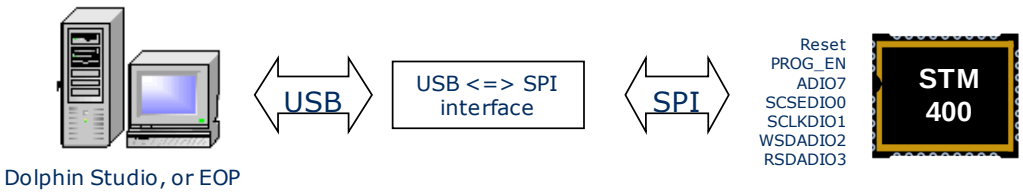
A radio telegram is always transmitted after wake-up via WAKE pins!
After transmission the counter is reset to a random value within the specified interval.

### 3.8.2 Configuration via programming interface

Via the programming interface the configuration area can be modified. This provides a lot more configuration options. Values set via programming interface override hardware settings! These settings are read after RESET or power-on reset only and not at every wake-up of the module!

| Parameter | Configuration via pins | Configuration via programming interface |
|---|---|---|
| Wake up cycle | See section 3.8.1 | Value can be set from 1 s to 65534 s |
| Redundant Retransmission cycle | See section 3.8.1 | Min…Max values for random interval<br>If Min=Max -> random switched off |
| Threshold values for analog inputs | No | The default values are: 5 LSB at AD_1 input, 6 LSB at AD_0 and 14 LSB at AD_2.<br>The threshold value can be set between 0 and full scale for every input individually. |
| Resolution of the analog inputs | No | Default: AD_0: 8 bit, AD_1: 8 bit, AD_2: 8 bit<br>Option: AD_0: 10 bit, AD_1: 6 bit, AD_2: 8 bit |
| Input mask | No | A digital input mask for ignoring changes on digital input pins. At default all input bits are checked. |
| Delay time between SCO on and sampling moment | No | Value can be set from 0 ms to 508 ms in steps of 2 ms. Default delay time is 2 ms. |
| Source of AD_2 | No | Select if AD_2 contains measurement value of external ADIO2 pin or from internal VDD/4 |
| Polarity of SCO signal | No | Polarity can be inversed. |
| Edge of wake pin change causing a telegram transmission | No | Every change of a wake pin triggers a wake-up. For both wake pins it can be configured individually if a telegram shall be sent on rising, falling or both edges. |
| Manufacturer ID and EEP (EnOcean Equipment Profile) | No | Information about manufacturer and type of device. This feature is needed for "automatic" interoperability of sensors and actuators or bus systems. Information how to set these parameters requires an agreement with EnOcean. Unique manufacturer IDs are distributed by the EnOcean Alliance. |

The interface is shown in the figure below:




EnOcean provides EOPX (EnOcean Programmer, a command line program) and Dolphin Studio (Windows application for chip configuration, programming, and testing) and the USB/SPI programmer device as part of the EDK 350 developer´s kit.

## 3.9 Radio telegram structure

### 3.9.1 Frame structure

Data is transmitted in frames.
Each frame is preceded by a preamble for bit synchronization and the generation of the data slicing thresholds.
After this a synchronization word is transmitted to enable the receiver to synchronize to the data bytes.
The first byte transmitted after the synchronization word represents the number of the data bytes transmitted as data payload.

### 3.9.2 Frame Parameters

The following table provides the parameters for the frame structure.

| Parameter | Value |
|---|---|
| Endianness | The MSB is transmitted first (Big-Endian). |
| Preamble | 16 bit 0b1010101010101010 (0xAAAA) |
| Synchronization Word | 16 bit 0b1010100100111100 (0xA93C) |
| Length | 1st Byte, containing the number of data bytes. |
| Data_PL | Bytes containing the transmitted data. |
| Minimum Number of Data Bytes | 1 |
| Maximum Number of Data Bytes[3] | 255 |

### 3.9.3 Data Payload (DATA_PL) Structure

The following illustration shows the structure of the data payload (content of the Data_PL field).

[3] Implementation platform EO3100I and EO1100I will only support 59 Data_PL bytes

### 3.9.4 Data Payload Parameters

#### 3.9.4.1 Header Parameters

The Header field is 8 bit long and contains information about ID-Sizes, availability of extended header and the telegram type. The following table provides the parameters for the header structure.

| Parameter | Value |
|---|---|
| Bit 5…7 Address Control | 000: Originator-ID 24 bit; no Destination-ID<br>001: Originator-ID 32 bit; no Destination-ID<br>010: Originator-ID 32 bit, Destination-ID 32 bit<br>011: Originator-ID 48 bit, no Destination-ID<br><br>100: reserved101: reserved110: reserved<br>111: reserved |
| Bit 4 Extended header available | 0: No extended header<br>1: Extended header available |
| Bit 0…3 Telegram type (R-ORG) | 0000: RPS telegram (0xF6)<br>0001: 1BS telegram (0xD5)<br>0010: 4BS telegram (0xA5)<br>0011: Smart Acknowledge Signal telegram (0xD0)<br>0100: Variable length data telegram (0xD2)<br>0101: Universal Teach-In EEP based (0xD4)<br>0110: Manufacturer Specific Communication (0xD1)<br>0111: Secure telegram (0x30)<br>1000: Secure telegram with encapsulation (0x31)<br>1001: Secure Teach-In telegram for switch (0x35)<br>1010: Generic Profiles selective data (0xB3)<br>1011: reserved<br>1100: reserved<br>1101: reserved<br>1110: reserved<br>1111: Extended Telegram type available |

#### 3.9.4.2 Extended Header

The Extended Header field is 8 bit long and contains information about optional data size and repeater count. The extended header will be added in a line powered device, if necessary. In an ultra low power device it is not needed. The following table provides the parameters for the extended header structure.

| Parameter | Value |
|---|---|
| Bit 4…7 Repeater count | 0: Original telegram<br>1…14: Telegram level repeated<br>15: Original telegram, do not repeat this telegram |
| Bit 0…3 Length of Optional data | 0000: No optional data field in frame<br>Other: Length of optional data field [Bytes] |

#### 3.9.4.3 Extended Telegram type

The Extended Telegram type field is available, if bits 0…3 in Header are all set. If not, the telegram type is specified in the header field and the extended telegram type field is not required. The following table provides the parameters for the extended header structure.

| Parameter | Value |
|---|---|
| Bit 0...7 Telegram type | 0x00: SYS_EX telegram (0xC5)<br>0x01: Smart Ack Learn request telegram (0xC6)<br>0x02: Smart Ack Learn Answer (0xC7)<br>0x03: Chained data message (0x40)<br>0x04: secure telegram (0x32)<br>0x05: Generic Profiles Teach-in request (0xB0)<br>0x06: Generic Profiles Teach-in response (0xB1)<br>0x07: Generic Profiles Complete data (0xB2)<br>0x08…0xFF: reserved for future use |

#### 3.9.4.4 Originator-ID

The Originator-ID field contains the module ID of the originator device. If the telegram is repeated, it still contains the originator ID and not the ID of the repeating device.
Due to the definition of the Address Control bits in the Header field, the length of the Originator-ID is 24, 32 or 48 bit.

#### 3.9.4.5 Destination-ID

The Destination-ID field is available dependent of the Address Control bits in the Header field. It contains the module ID of the destination device. Due to the definition of the Address Control bits in the Header field, the length of the Destination-ID is 32 or 48 bit.

#### 3.9.4.6 Data_DL

The Data_DL field contains the payload of the telegram.

#### 3.9.4.7 Optional Data

The Optional Data field is available dependent of the Bits 0…3 in the Extended Header field; the size is defined there as well.

For each telegram type the content and the length of Data_DL may be different.
Today's applications have to be compliant with later versions of the Advanced protocol ensuring an upwards compatibility.
New software applications or devices might require the definition of additional data. This data can be transmitted in the Optional Data fields, e.g. a sub telegram counter.
Thus, backwards compatibility is secured.

#### 3.9.4.8 CRC

The CRC field is 8 bit. Each byte of Data_PL is used to calculate the CRC (Length is not used). The algorithm is described in [2] Chapter 7.3.3.

### 3.9.5 Link Layer Data (DATA_DL)

#### 3.9.5.1 Link Layer Data (DATA_DL) for Normal Operation

Telegram content seen at programming interface of STM 400 or at DOLPHIN API:

**RORG** = 0xA5 (Telegram type "4BS")

**Data_Byte1..3**
3x8bit mode:

DATA_BYTE3 = Value of AD_2 analog input
DATA_BYTE2 = Value of AD_1 analog input
DATA_BYTE1 = Value of AD_0 analog input

1x8bit, 1x6it, 1x10bit mode:

DATA_BYTE3 = Value of AD_2
DATA_BYTE2 = Upper 2 bits of AD_0 and value of AD_1
DATA_BYTE1 = Lower 8 bits Value of AD_0 analog input

| DATA_BYTE3 | | | | | | | | DATA_BYTE2 | | | | | | | | DATA_BYTE1 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AD_2 | | | | | | | | AD_1 | | | | | | AD_0 | | | | | | | | | |
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | 5 | 4 | 3 | 2 | 1 | 0 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |

**DATA_BYTE0** = Digital input Status

| Bit 7 | | | | Bit 0 |
|---|---|---|---|---|
| Reserved, set to 0 | DI_3 | DI_2 | DI_1 | DI_0 |

DI_3 = Status of digital input 3
DI_2 = Status of digital input 2
DI_1 = Status of digital input 1
DI_0 = Status of digital input 0

The voltages measured at the analog inputs can be calculated from these values as follows:

$U=(\text{Value of AD_x})/(2^n)\text{x}1.8\ \text{V}$ n=resolution of channel in bit

#### 3.9.5.2 Link Layer Data (DATA_DL) for Teach-in Telegrams

In case a manufacturer code is programmed into the module the module transmits – instead of transmitting a normal telegram – a dedicated teach-in telegram if

- digital input DI_3=0 at wake-up or
- wake-up via WAKE1 pin (LRN input)

With this special teach-in telegram it is possible to identify the manufacturer of a device and the function and type of a device. There is a list available from the EnOcean Alliance describing the functionalities of the respective products.

If no manufacturer code is programmed the module does not react to signal changes on WAKE1 (LRN input)!

RORG = 0xA5 (Telegram type "4BS")

DATA_BYTE0..3 see below
Function, Type, Manufacturer-ID: Defined by manufacturer
LRN Type = 1
RE0..2: set to 0
LRN = 0
DI0..DI2: current status of digital inputs

| Data_Byte3 | Data_Byte2 | Data_Byte1 | Data_Byte0 |
|---|---|---|---|

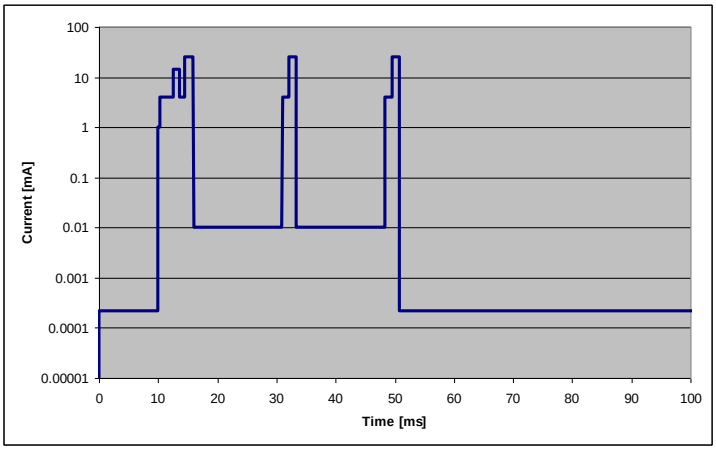
| Function 6 Bit | Type 7 Bit | Manufacturer-ID 11 Bit | LRN Type 1Bit | RE2 1Bit | RE1 1Bit | RE0 1Bit | LRN 1Bit | DI2 1Bit | DI1 1Bit | DI0 1Bit |
|---|---|---|---|---|---|---|---|---|---|---|

## 3.10 Transmit timing

The setup of the transmission timing allows avoiding possible collisions with data packages of other EnOcean transmitters as well as disturbances from the environment. With each transmission cycle, 3 identical subtelegrams are transmitted within 40 ms. Transmission of a subtelegram lasts approximately 1.2 ms. The delay time between the three transmission bursts is affected at random.

If a new wake-up occurs before all sub-telegrams have been sent, the series of transmissions is stopped and a new series of telegrams with new valid measurement values is transmitted.

## 3.11 Energy consumption




Typical Current Consumption of STM 400 during TX

Charge needed for one measurement and transmit cycle: ~130 µC
Charge needed for one measurement cycle without transmit: ~30 µC
(current for external sensor circuits not included)

Calculations are performed on the basis of electric charges because of the internal linear voltage regulator of the module. Energy consumption varies with voltage of the energy storage while consumption of electric charge is constant.
From these values the following performance parameters have been calculated:

| Wake cycle [s] | Transmit interval | Operation Time in darkness [h] when storage fully charged | Required reload time [h] at 200 lux within 24 h for continuous operation | 24 h operation after 6 h illumination at x lux | Illumination level in lux for continuous operation | Current in µA required for continuous operation |
|---|---|---|---|---|---|---|
| 1 | 1 | 0.5 | storage too small | storage too small | 5220 | 130.5 |
| 1 | 10 | 1.7 | storage too small | storage too small | 1620 | 40.5 |
| 1 | 100 | 2.1 | storage too small | storage too small | 1250 | 31.3 |
| 10 | 1 | 5.1 | storage too small | storage too small | 540 | 13.5 |
| 10 | 10 | 16 | 21 | storage too small | 175 | 4.4 |
| 10 | 100 | 20 | 16.8 | storage too small | 140 | 3.5 |
| 100 | 1 | 43 | 7.8 | 260 | 65 | 1.6 |
| 100 | 10 | 98 | 3.6 | 120 | 30 | 0.8 |
| 100 | 100 | 112 | 3 | 100 | 25 | 0.6 |

Assumptions:

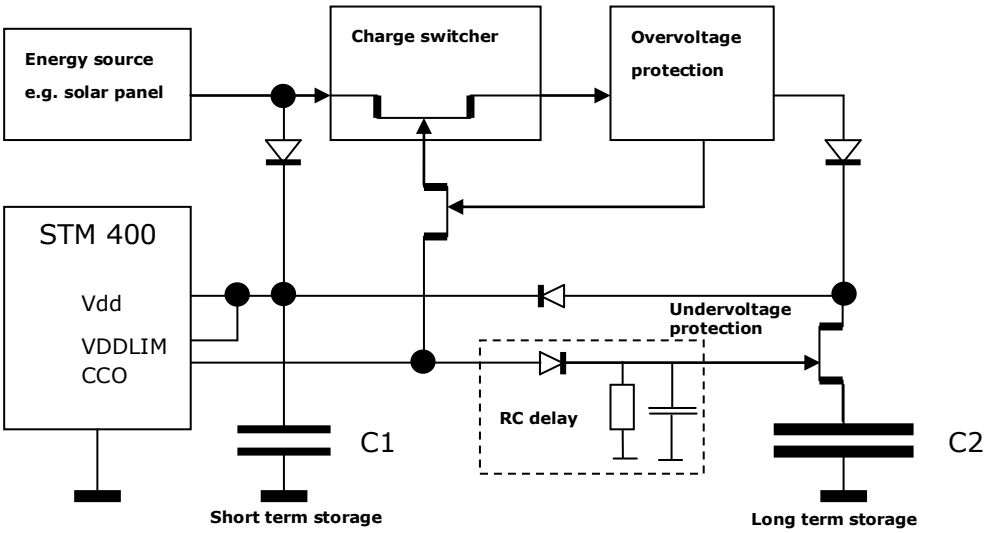
- Storage PAS614L-VL3 with 0.25 F, Umax=3.2 V, Umin=2.2 V, T=25°C
- Consumption: Transmit cycle 100 µC, measurement cycle 30 µC
- Indoor solar cell, operating values 3 V and 5 µA @ 200 lux fluorescent light (e.g. ECS 300 solar cell)
- Current proportional to illumination level (not true at very low levels!)

These values are calculated values, the accuracy is about +/-20%!

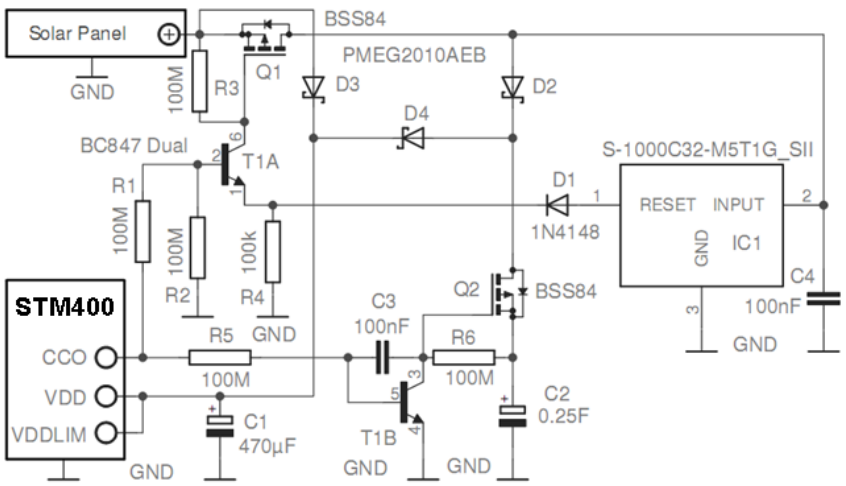
# 4 APPLICATIONS INFORMATION

## 4.1 How to connect an energy harvester and energy storage

STM 400 is designed for use with an external energy harvester and energy storage.
In order to support a fast start-up and long term operation with no energy supply available usually two different storages are used. The small storage fills quickly and allows a fast start-up. The large storage fills slowly but once it is filled up it provides a large buffer for times where no energy is available, e.g. at night in a solar powered sensor.
STM 400 provides a digital output CCO (see also 3.7) which allows controlling the charging of these two storages. At the beginning, as long as the voltage is below the VON voltage only the small storage is filled. Once the threshold is reached the CCO signal changes and the large storage is filled. The short term storage capacitor (C1) is usually in the range of 470 to 1000 µF. For the long term storage we suggest a capacitor (C2) with a capacity of 0.25 F. Below an overview and the schematics of a charging circuitry is shown:




This circuit is designed for an energy storage capacitor specified for 3.3 V (e.g. PAS614L-VL3. Please pay great attention to manufacturers handling and soldering procedures!)



### Charge switcher

The charge switcher connects both short term storage and long term storage parallel to the energy source as soon as the STM 400 supply voltage reaches the typical VON threshold of 2.45 V. Supposing VDD then falls below VON, the energy source will be switched back to short term storage alone, for faster recharging. As long as the voltage on long term storage remains below VON, the charge switcher will continuously switch the energy source between short term and long term storage, trying to ensure continuous device operation. That is because of the higher resistance and capacitance of long term storage, which would lead to much too long charging (i.e. non-operative time). In addition short term storage cannot be charged over this threshold until the voltage on long term storage exceeds VON. Charge switcher is the PMOS transistor Q1, driven from the STM 400 charge control output CCO over T1A. To start with, as long as the STM 400 VDD voltage is below the VON threshold, only the small storage (C1) is filled over D3. Once the threshold is reached, the CCO control signal goes High, T1B and Q2 are turned on and the long term storage (C2) will be filled over Q2.

### Overvoltage protection

All of these long term storage solutions have a rated operating voltage that must be not exceeded. After reaching this limit the energy source is automatically separated from storage to avoid any damage. Overvoltage protection is implemented by the S-1000C32-M5T1x voltage detector from Seiko (SII) or the NCP300LSN30T1G series (ON Semiconductor), which limits the maximum charging voltage to 3.3 V to avoid damaging long term energy storage. In case a different voltage limit is required, this device has to be replaced by a suitable voltage variant. As soon as the voltage on D2 anode or the voltage detector input exceeds the selected threshold, the voltage detector delivers a High level on its output connected to the T1A emitter. The T1A base is consequently lower polarized than its emitter and the transistor is turned off. That means Q1 is turned off too — the energy source is switched off and long term storage is protected.

The selected voltage detector must have a very low quiescent current in the operating range, and an appropriate threshold voltage, corresponding to the selected long term energy storage voltage (e.g. threshold nominally 3.2 V for a 3.3 V capacitor). If the selected threshold is too low, e.g. 3.0 V, a relatively high amount of energy corresponding to a useful voltage difference of 0.3 V would be wasted. If the nominal threshold is too high, e.g. exactly 3.3 V (not forgetting that this could reach 3.4 V as a result of additional manufacturer tolerances), it could be critical for energy storage life expectation. The S-1000C32-M5T1x voltage detector consequently looks like the best compromise here (rated 3.2 V)

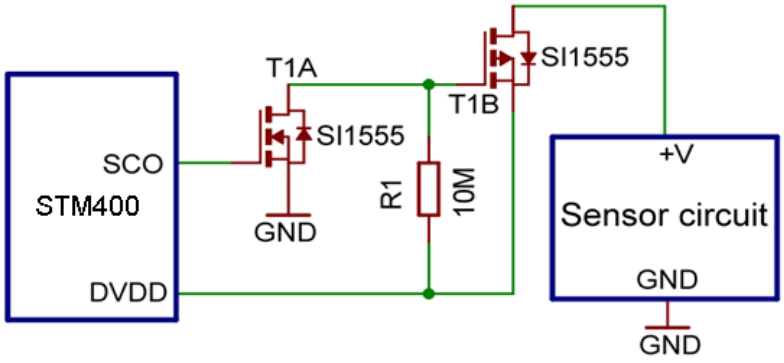
### Undervoltage protection

PAS capacitors should not be deep discharged to voltages below 1.5 V. To avoid long term degradation of their capacity and lifetime, an undervoltage protection block is added. Undervoltage protection is also implemented through Q2. In normal operation, when VDD reaches the VON threshold, the STM 400 charge control CCO goes high, T1B rapidly discharges C3 to GND and Q2 turns on long term storage. The C3 charge recovers very slowly over R6, so Q2 cannot turn off long term storage immediately. Only if VDD falls below VOFF for a longer time does C3 have time to recover and finally to turn off Q2 and thus the long term storage path (over D4) from the STM 400, avoiding deep discharge.

For more details and alternative circuits please refer to application note AN208.

## 4.2 Using the SCO pin

STM 400 provides an output signal at SCO which is suited to control the supply of the sensor circuitry. This helps saving energy as the sensor circuitry is only powered as long as necessary. In the default configuration SCO provides a HIGH signal 2 ms (delay time) before the analog inputs are read. Via the programming interface (see 3.8.2) it is possible to adjust the delay time and also the polarity of the signal.




The figure above shows, how the SCO pin (with default polarity) can be used to control an external sensor circuit.

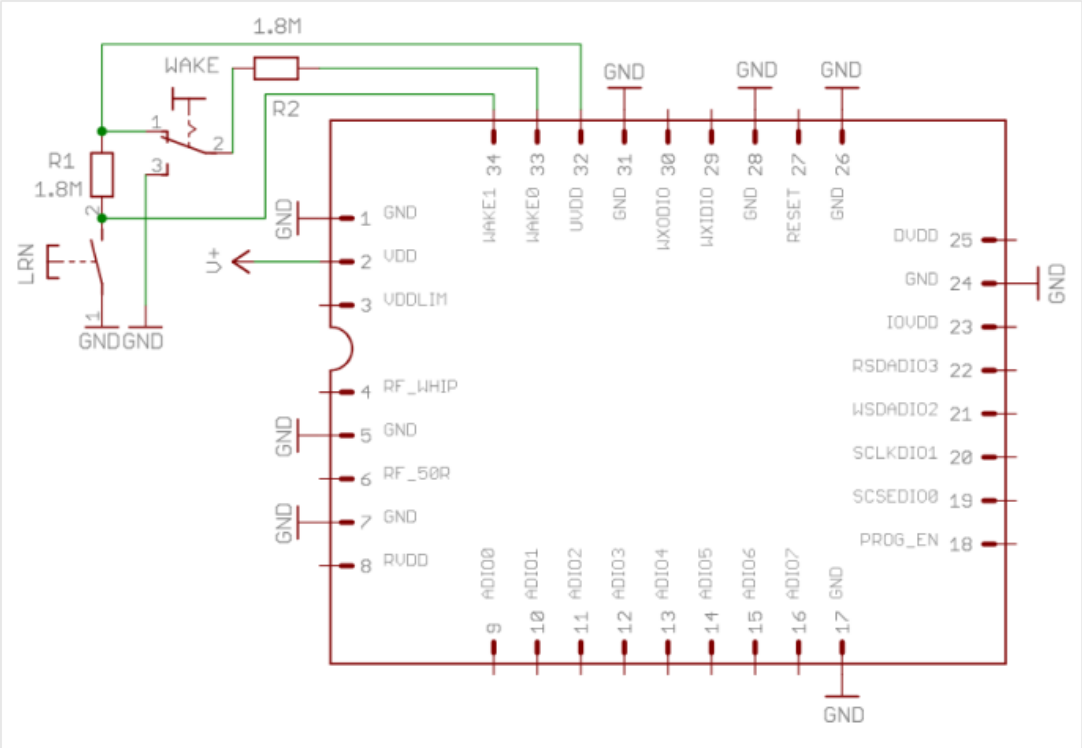
Do not supply sensors directly from SCO as this output can only provide maximum 15 µA!

## 4.3 Using the WAKE pins

The logic input circuits of the WAKE0 and WAKE1 pins are supplied by UVDD and therefore also usable in "Deep Sleep Mode" or "Flywheel Sleep Mode" (via API only). Due to current minimization there is no internal pull-up or pull-down at the WAKE pins.
When STM 400 is in "Deep Sleep Mode" or "Flywheel Sleep Mode" (via API only) and the logic levels of WAKE0 and / or WAKE1 is changed, STM 400 starts up.

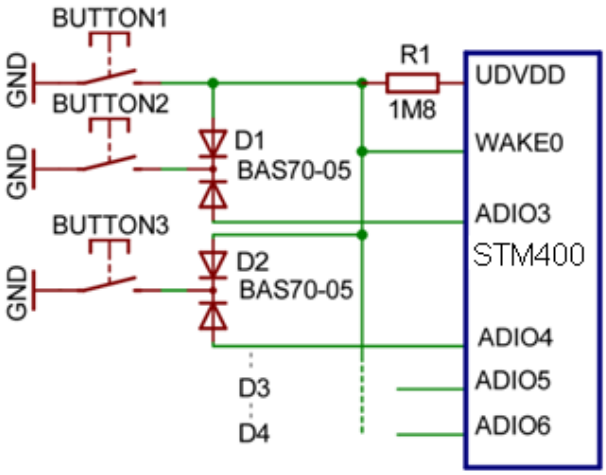
As the there is no internal pull-up or pull-down at the WAKE pins, it has to be ensured by external circuitry, that the WAKE pins are at a defined logic level at any time.

When using the UVDD regulator output as source for the logic HIGH of the WAKE pins, it is strongly recommended to protect the ultra low power UVDD voltage regulator against (accidental) excessive loading by connection of an external 1.8 MΩ series resistor.




The figure above shows two examples how the WAKE inputs may be used. When the LRN button is pressed WAKE1 is pulled to GND and a teach-in telegram is transmitted.
As long as the button is pressed a small current is flowing from UVDD to GND.
WAKE0 is connected to a toggle switch. There is no continuous flow of current in either position of the switch.

If more digital inputs with WAKE functionality are needed in an application, WAKE0 can be combined with some of the digital inputs as shown below:



## 4.4 Using RVDD

If RVDD is used in an application circuit a serial ferrite bead shall be used and wire length should be as short as possible (<3 cm). The following ferrite beads have been tested: 74279266 (0603), 74279205 (0805) from Würth Elektronik. During radio transmission and reception only small currents may be drawn (I<100 µA).
Pulsed current drawn from RVDD has to be avoided. If pulsed currents are necessary, sufficient blocking has to be provided.

## 4.5 Antenna options STM 400

### 4.5.1 Overview

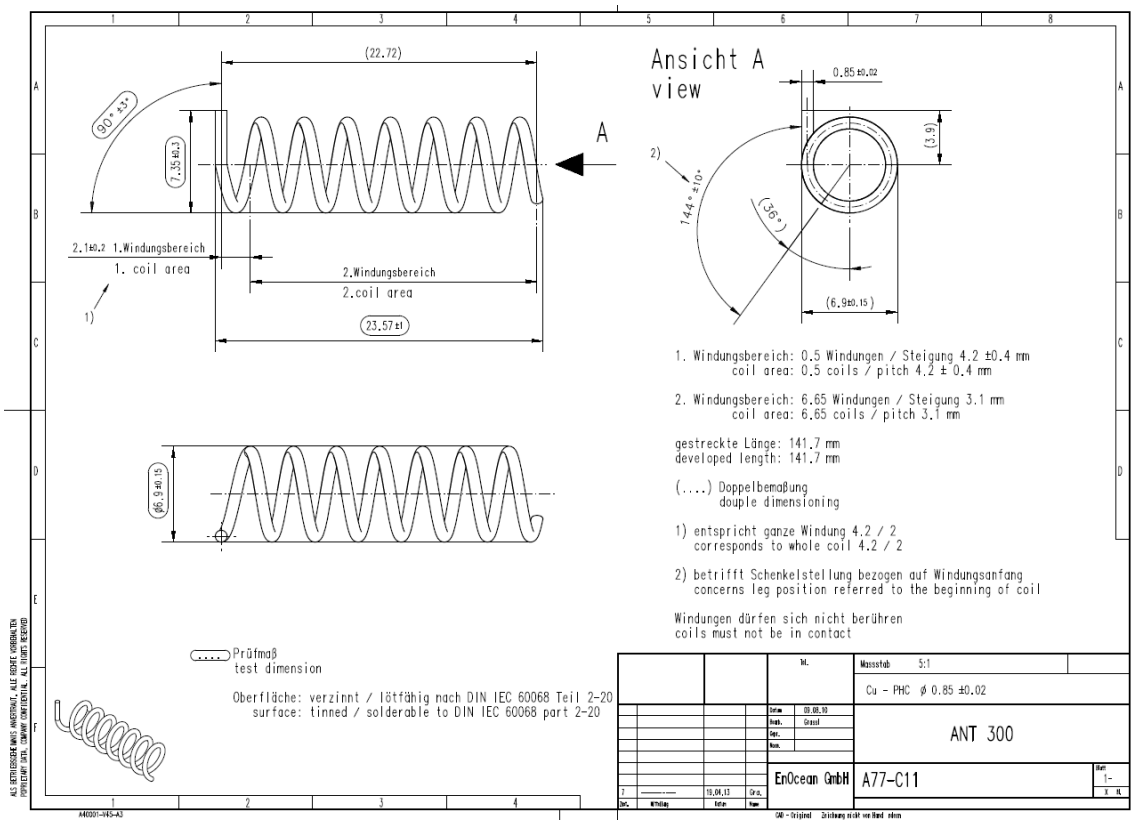
Several antenna types have been investigated by EnOcean. Please refer to our application notes AN102, and AN105 which give an overview on our recommendations.

### 4.5.2 Whip antenna

**928.35 MHz**
Antenna: 64 mm wire, connect to RF_WHIP
Minimum GND plane: 50 mm x 50 mm
Minimum distance space: 10 mm

### 4.5.3 Helical antenna

**928.35 MHz**
according to drawing below, connect to RF_WHIP
Minimum GND plane: 35 mm x 30 mm
Minimum distance space: 10 mm



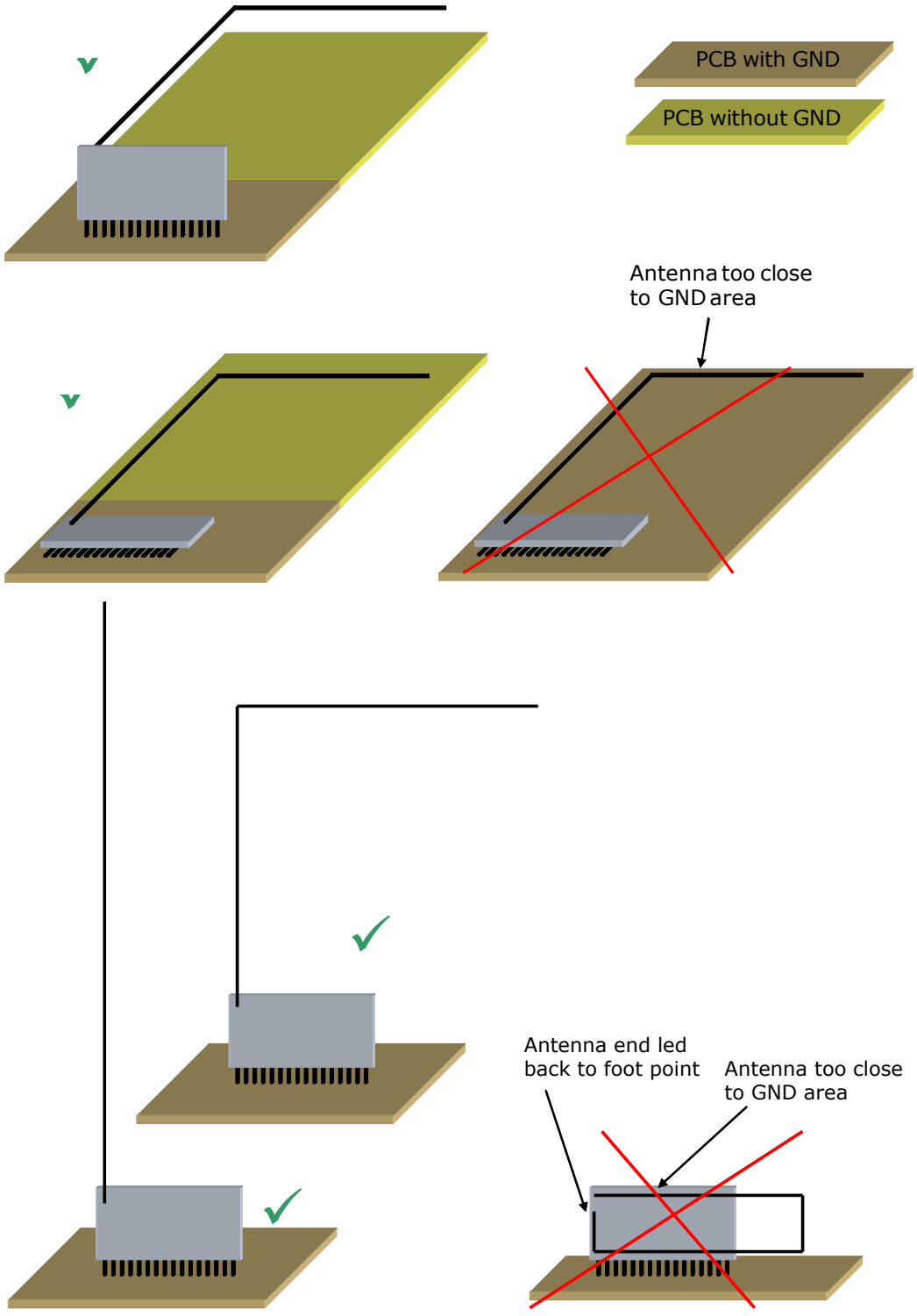
## 4.6 Positioning of the whip antenna

Positioning and choice of receiver and transmitter antennas are the most important factors in determining system transmission range.

For good receiver performance, great care must be taken about the space immediately around the antenna since this has a strong influence on screening and detuning the antenna. The antenna should be drawn out as far as possible and must never be cut off. Mainly the far end of the wire should be mounted as far away as possible (at least 15 mm) from all metal parts, ground planes, PCB strip lines and fast logic components (e.g. microprocessors).
Do not roll up or twist the whip antenna!

Radio frequency hash from the motherboard desensitizes the receiver. Therefore:
- PCB strip lines on the user board should be designed as short as possible
- A PCB ground plane layer with sufficient ground vias is strongly recommended

## 4.7 Recommendations for laying a whip antenna



## 4.8 Layout recommendations for foot pattern

The length of lines connected to I/Os should not exceed 5 cm.

It is recommended to have a complete GND layer in the application PCB, at least in the area below the module and directly connected components (e.g. mid-layer of your application PCB).

Due to unisolated test points there are live signals accessible on the bottom side of the module.

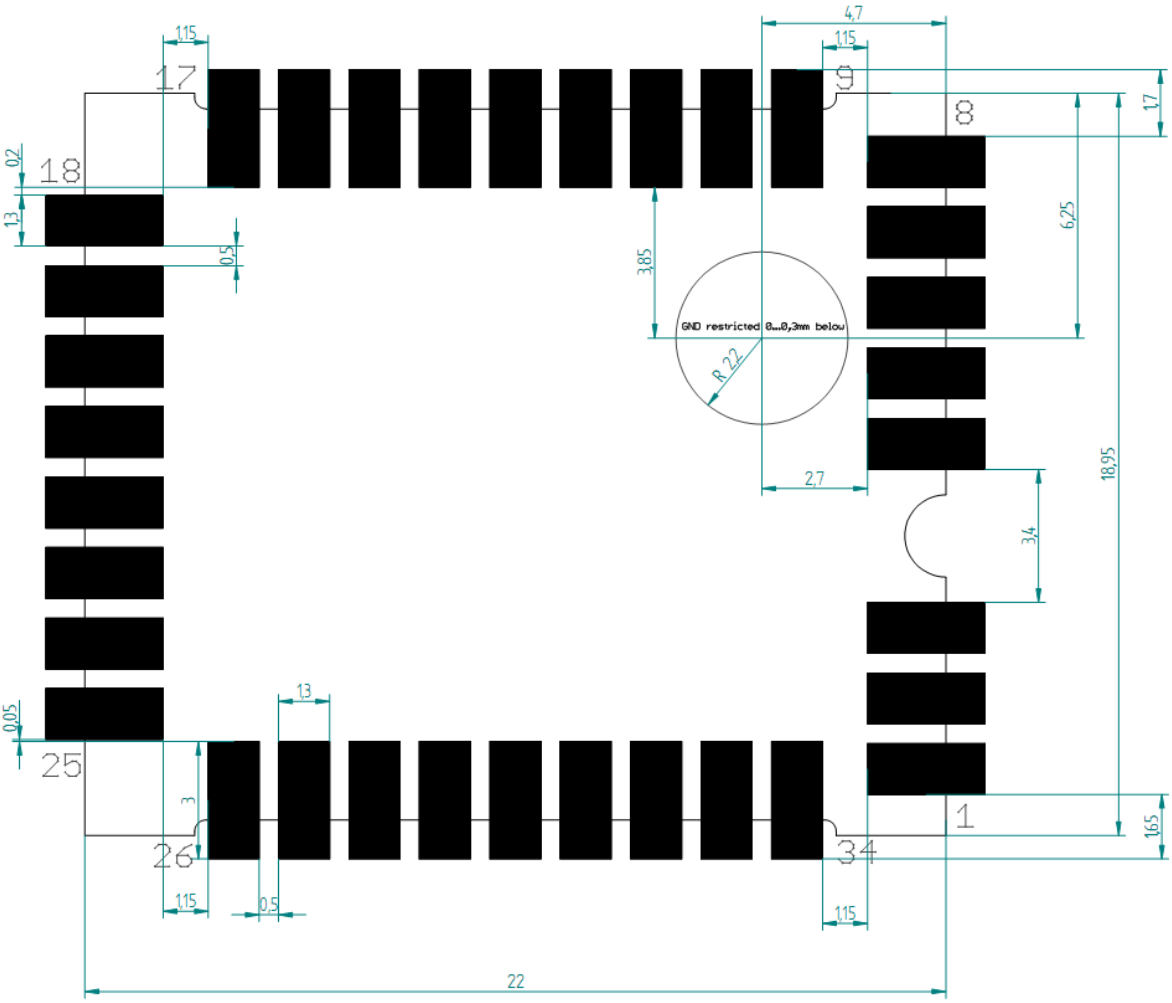
Please follow the following advices to prevent interference with your application circuit:

- We suggest avoiding any copper structure in the area directly underneath the module (top-layer layout of your application PCB). If this is not possible in your design, please provide coating on top of your PCB to prevent short circuits to the module. All bare metal surfaces including vias have to be covered (e.g. adequate layout of solder resist).
- It is mandatory that the area marked by the circle in the figure below is kept clear of any conductive structures in the top layer and 0.3 mm below. Otherwise RF performance will be degraded!

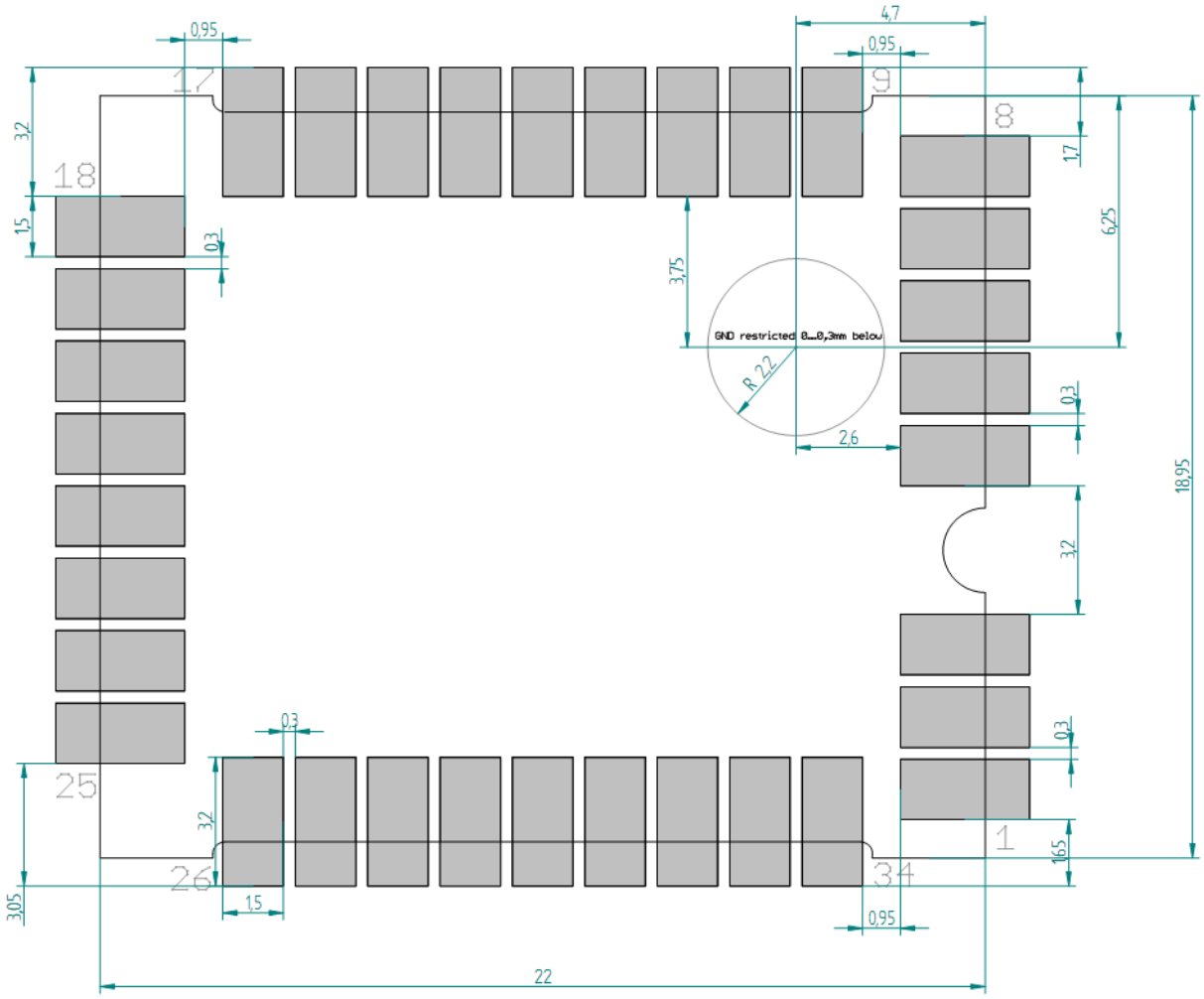
Furthermore, any distortive signals (e.g. bus signals or power lines) should not be routed underneath the module. If such signals are present in your design, we suggest separating them by using a ground plane between module and these signal lines.

The RVDD line should be kept as short as possible. Please consider recommendations in section 4.4.

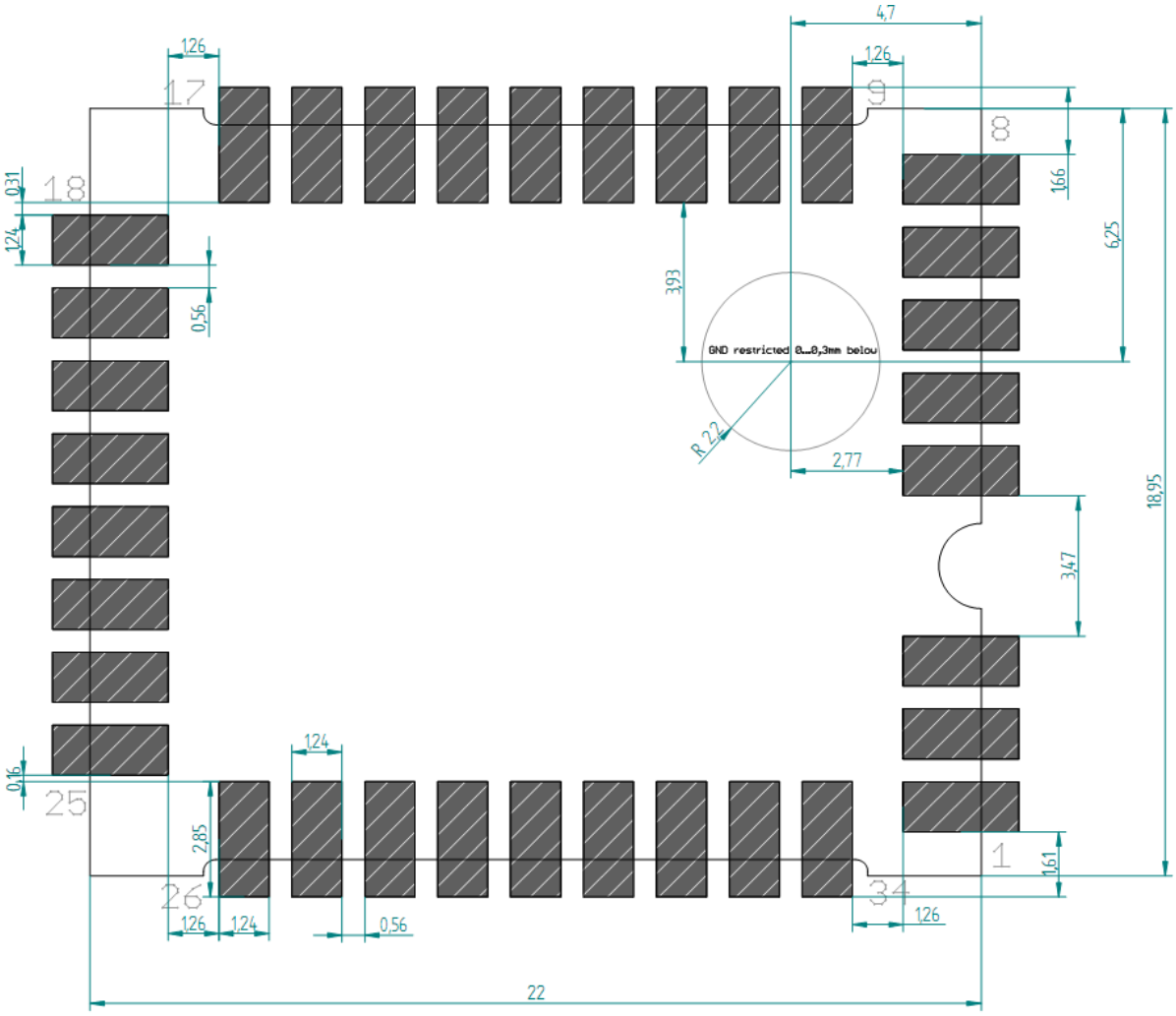
**Top layer**


4,7
1,15
1,15
17
9
8
18
0,2
1,3
0,5
3,85
6,25
1,7
GND restricted 0...0,3mm below
R 2,2
2,7
18,95
3,4
0,05
1,3
25
3
26
1
34
1,65
1,15
0,5
1,15
22

**Solder resist top layer**



**Solder paste top layer**




The data above is also available as EAGLE library.

In order to ensure good solder quality a solder mask thickness of 150 µm is recommended.

In case a 120 µm solder mask is used, it is recommended to enlarge the solder print. The pads on the solder print should then be 0.1 mm larger than the pad dimensions of the module as specified in chapter 2.3. (not relative to the above drawing).

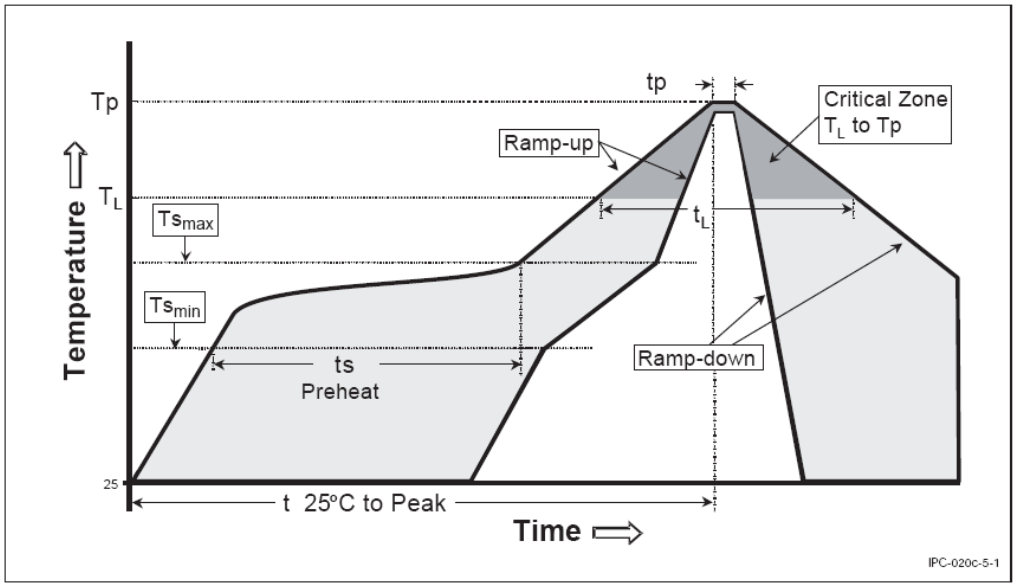
Nevertheless an application and production specific test regarding the amount of soldering paste should be performed to find optimum parameters.

## 4.9 Soldering information

STM 400 has to be soldered according to IPC/JEDEC J-STD-020C standard.

| Profile Feature | Pb-Free Assembly |
|---|---|
| Average Ramp-Up Rate ($Ts_{max}$ to Tp) | 3° C/second max. |
| **Preheat**<br>– Temperature Min ($Ts_{min}$)<br>– Temperature Max ($Ts_{max}$)<br>– Time ($ts_{min}$ to $ts_{max}$) | <br>150 °C<br>200 °C<br>60-180 seconds |
| Time maintained above:<br>– Temperature ($T_L$)<br>– Time ($t_L$) | <br>217 °C<br>60-150 seconds |
| Peak/Classification Temperature (Tp) | 260 °C |
| Time within 5 °C of actual Peak Temperature (tp) | 20-40 seconds |
| Ramp-Down Rate | 6 °C/second max. |
| Time 25 °C to Peak Temperature | 8 minutes max. |

**Note 1:** All temperatures refer to topside of the package, measured on the package body surface.



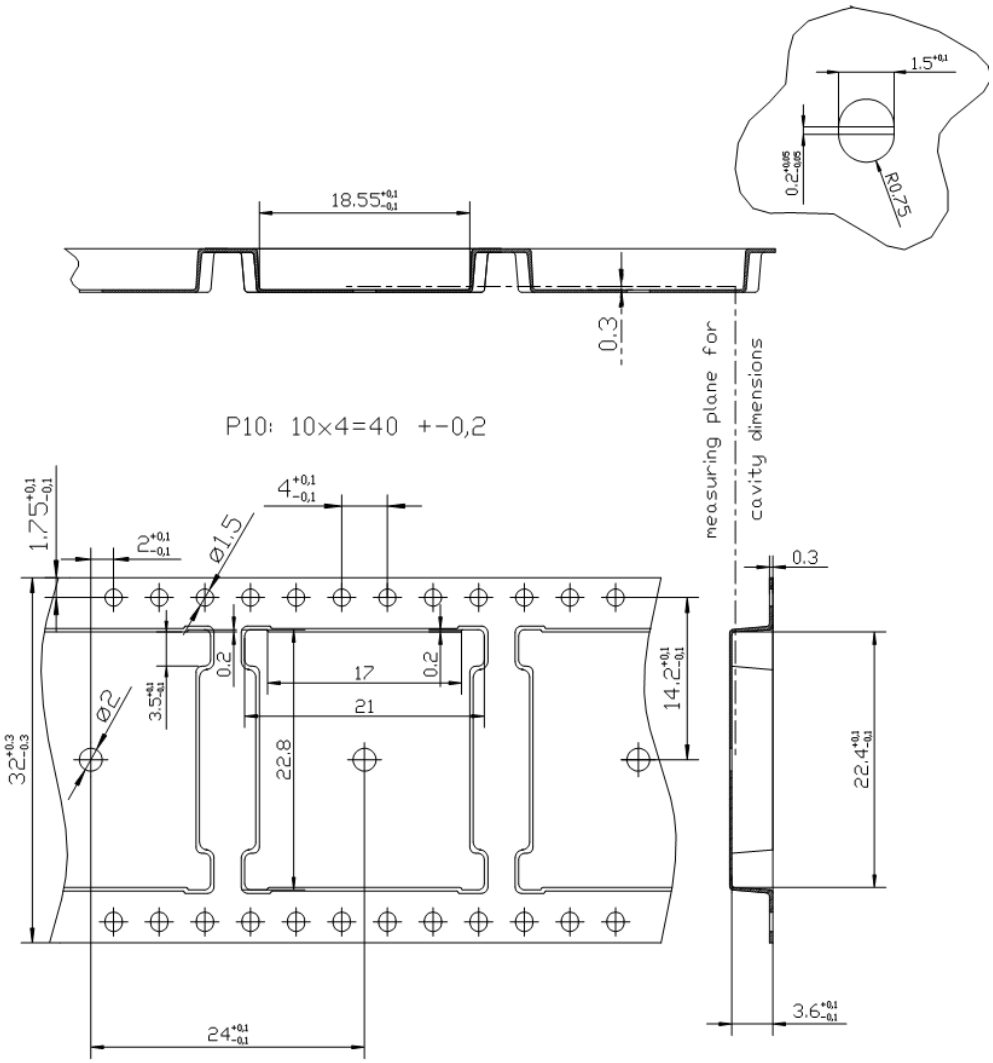

STM 400 shall be handled according to Moisture Sensitivity Level MSL4 which means a floor time of 72 h. STM 400 may be soldered only once, since one time is already consumed at production of the module itself.

Once the dry pack bag is opened, the desired quantity of units should be removed and the bag resealed within two hours. If the bag is left open longer than 30 minutes the desiccant should be replaced with dry desiccant. If devices have exceeded the specified floor life time of 72 h, they may be baked according IPC/JEDEC J-STD-033B at max. 90°C for less than 60 h.

Devices packaged in moisture-proof packaging should be stored in ambient conditions not exceeding temperatures of 40 °C or humidity levels of 90% r.h.

STM 400 modules have to be soldered within 6 months after delivery!

## 4.10 Tape & Reel specification



Tape running direction

## 4.11 Transmission range

The main factors that influence the system transmission range are type and location of the antennas of the receiver and the transmitter, type of terrain and degree of obstruction of the link path, sources of interference affecting the receiver, and "Dead" spots caused by signal reflections from nearby conductive objects. Since the expected transmission range strongly depends on this system conditions, range tests should categorically be performed before notification of a particular range that will be attainable by a certain application.

The following figures for expected transmission range are considered by using a PTM, a STM or a TCM radio transmitter device and the TCM radio receiver device with preinstalled whip antenna and may be used as a rough guide only:

- Line-of-sight connections: Typically 30 m range in corridors, up to 100 m in halls
- Plasterboard walls / dry wood: Typically 30 m range, through max. 5 walls
- Line-of-sight connections: Typically 30 m range in corridors, up to 100 m in halls
- Ferroconcrete walls / ceilings: Typically 10 m range, through max. 1 ceiling
- Fire-safety walls, elevator shafts, staircases and supply areas should be considered as screening.

The angle at which the transmitted signal hits the wall is very important. The effective wall thickness – and with it the signal attenuation – varies according to this angle. Signals should be transmitted as directly as possible through the wall. Wall niches should be avoided. Other factors restricting transmission range:

- Switch mounted on metal surfaces (up to 30% loss of transmission range)
- Hollow lightweight walls filled with insulating wool on metal foil
- False ceilings with panels of metal or carbon fiber
- Lead glass or glass with metal coating, steel furniture

The distance between EnOcean receivers and other transmitting devices such as computers, audio and video equipment that also emit high-frequency signals should be at least 0.5 m

A summarized application note to determine the transmission range within buildings is available as download from www.enocean.com.

# 5 AGENCY CERTIFICATIONS

The modules have been tested to fulfil the approval requirements based on the built-in firmware.

**When developing customer specific firmware based on the API for this module, special care must be taken not to exceed the specified regulatory limits, e.g. the duty cycle limitations!**

## 5.1 Japanese Type Approval

STM 400J complies with the Japanese radio law and is certified according to ARIB STD-T108. Upon completion of certification it will cover the certification ID on the back side label (MIC marking).
If the certification label cannot be recognized from outside (e.g. installation in a host) appropriate information must be referenced in the user manual.